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Cartels: the Probability of Getting Caught in the European Union

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Abstract

In 1991, Bryant and Eckard estimated the annual probability that a cartel would be detected by the US Federal authorities, conditional on being detected, to be at most between 13 % and 17 %. 15 years later, we estimated the same probability over a European sample and we found an annual probability that falls between 12.9 % and 13.3 %. We also develop a detection model to clarify this probability. Our estimate is based on detection durations, calculated from data reported for all the cartels convicted by the European Commission from 1969 to the present date, and a statistical birth and death process model describing the onset and detection of cartels.

En 1991, Bryant et Eckard estiment que la probabilité annuelle de détection des cartels qui seront finalement détectés par les autorités de concurrence américaines, se situe entre 13 et 17 %. 15 ans après, nous estimons cette probabilité sur un échantillon européen, et nous trouvons que cette probabilité se situe entre 12,9 et 13,3 %. De plus, nous développons un modèle de détection des cartels nous permettant d'expliciter cette probabilité. Notre estimation est basée sur les durées de détection de tous les cartels condamnés par la Commission européenne depuis 1969, et sur un modèle statistique de processus de vie et de mort décrivant la naissance et la détection des cartels.

Keywords: Cartels, Duration Analysis, Birth and Death Process.

JEL codes: L41, C34, C41.

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1. Introduction

The probability of detection plays a key role in the economics of crime, particularly in the literature related to optimal sanctions to be imposed on lawbreakers. Thus, in competition economics, particularly in studies on cartel dissuasion, this parameter is used to compute the optimal fine to be imposed on cartel members, so as to deter their formation. In a Beckerian perspective[1], crime dissuasion implies that the illegal profit made by the cartel or damage caused to society[2], is equal or inferior to the expected fine – which corresponds to average fine times the probability of getting caught. This value is very important to managers willing to join or create a cartel. The probability of detection is a determinant parameter of their utility function as cartel formation relates to decision making under uncertainty. Therefore, the estimation of cartels probability of detection is a crucial issue for antitrust authorities, in the view of designing an optimal policy regarding the fight against cartels.

Unfortunately, very few studies are available on that subject. Bryant and Eckard (1991) were the first - and to the present date the sole - to estimate rigorously the probability of cartel detection. Their estimation was based on an American sample of cartels indicted by the DOJ[3] between 1961 and 1988. Their paper became the most quoted work on this issue. Nevertheless, the results were often improperly quoted. In particular, in the literature related to optimal fines, the authors often refer to a value of 15 %, as the

1 Cf. Becker (1968).

2 Cf. Combe & Monnier (2007a). In the crime theory, the usual base is the damage caused to society, as it ensures that only efficient crimes occur – crimes for which the benefit from breaking the law exceeds the cost endured by the victims. In the specific case of a cartel, the illicit gain is always inferior to the damage inflicted to consumers - except in the case where price elasticity is zero, which implies that the two values are equal. Therefore, it seems more accurate to use the illegal profit as the agent decision to break the law depends on the expected net illegal gain, and not on the inflicted damage. For instance, this choice is the one made by Werden & Simon (1987).

3 Department of Justice.

average probability of getting caught, as Bryant and Eckard estimated a probability that falls between 13 % and 17 %. But this 15 % rate is the annual probability of getting caught… for cartels which will eventually be detected. This feature can be explained by the fact that the sample on which was based their estimation comprised only convicted cartels, as - by definition - no data exists on cartels that went undetected. Thus, the estimated probability is not the global probability of detection. It is the probability of detection conditional on being detected on a given period. It is an upper bound of the global probability of detection in a given period and it is positively related to it.

In this article, we will first present a model of cartel detection, so as to clarify the different processes and probabilities at stake- later on, it will allow us to interpret rigorously our estimates and to draw our conclusions. Second, we will explain the methodology used, regarding data collection and statistical processing. Last, we will expose and analyze our estimation and results.

2. Cartel detection model

2.1. Hypothesis

Bryant and Eckard (1991) introduced a birth and death process to describe the dynamic that governs N(t), the number of cartels alive at time t. We also model cartel detection using this framework. However, contrary to these authors, in the following model, we consider three processes: one related to cartel birth, another to their natural death, and the last one governs their detection. Some cartels are detected while still active, and we suppose that detection triggers the breakup of the cartel- due to antitrust intervention. In other cases, cartels are detected *ex post* - i.e. after their death. Cartel lifetime is therefore deemed "natural".[4]

We must specify the three processes chosen - birth process, death process, detection process. First, we consider that cartels appear ones after the others according to a random variable. We denote A_i the time between the birth of the $(i-1)^{th}$ cartel and the birth of the i^{th} cartel - inter-arrival times between the birth of successive cartels - and we hypothesize that the $(A_i)_{i>0}$ are independently and exponentially distributed with mean $(1/\theta)$. Second, we suppose that each cartel i has a natural lifetime $D_i=D$, independently and exponentially distributed with mean $1/\Lambda$. Last, we hypothesize that at a given time

[4] As for them, Bryant & Eckard equate cartel death to detection - and therefore consider that cartel lifetime systematically equals the time required to detect the cartel.

t, when the i^{th} cartel appears, if n describes the number of cartels that will be detected, but not yet detected at time t, our new-born cartel has a q_n probability to be subjected to the detection process (event E) and therefore to be detected *in fine*, and a (1-q_n) probability not to be subjected to this process and hence to remain unknown (event $\bar{E}$).[5] In this latter case, the cartel will never be detected and will end due to natural causes.

We suppose that the sequence $(q_n)_{n\in N}$ is decreasing[6] and by the way of example that:

$$\forall n \in \mathbb{N}, q_n = \frac{1}{n+1}$$

If for the i^{th} cartel born, the event E occurs, we suppose that the cartel is immediately subjected to the detection process. Therefore, at time t, we have N(t) cartels under investigation and there are all subjected to the detection process. We define this process in the following way: if we consider a cartel i that will get detected and if we denote L_i the duration between its birth and its detection, we suppose that for any i, L_i is exponentially distributed with mean (1/λ). Thus, cartels for which event E occurs, have a mean detection duration of (1/λ) and an instantaneous detection probability of λ. Finally, given the limited capacity of antitrust authorities - because of budget and legal constraints - we suppose that only N_{max} cartels at most can be investigated at the same time, i.e. N(t) is bounded by N_{max}.

2.2. Main results in steady state

We observe the system in steady state, a long time after the three processes have begun, so that initial conditions (starting date of the process for instance) have no incidence on the final result. We can classify cartels into three subpopulations:

- undetected cartels: population Ω_1
- cartels detected *ex post* (after their natural death): denoted population Ω_2
- cartels detected alive: denoted population Ω_3

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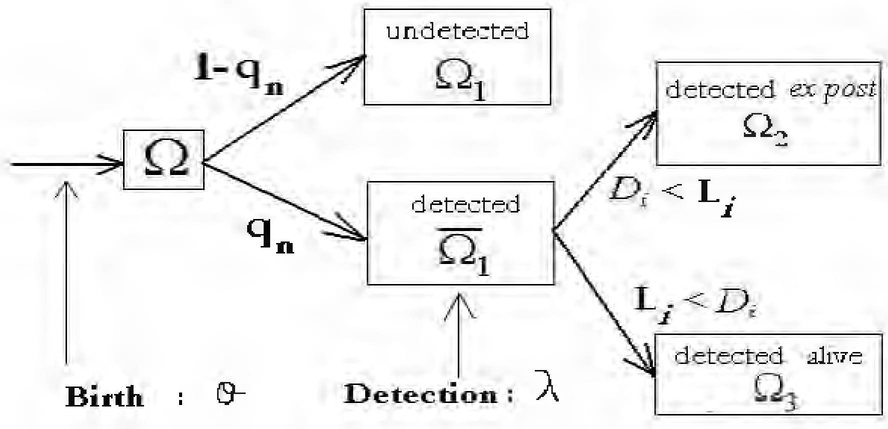
5 Our framework is similar to a queuing model with discouragement: the service time corresponds to the duration required to detect the cartel and discouragement relates to cartels that will not be detected by antitrust authorities, as some cartels will never be detected - given the budget constraint and the limited investigation power of antitrust authorities.

6 Indeed, when a new cartel appears, the greater the number of cartels already under investigation, the lower the probability that this new cartel will be subjected to the detection process - antitrust authorities being busy.

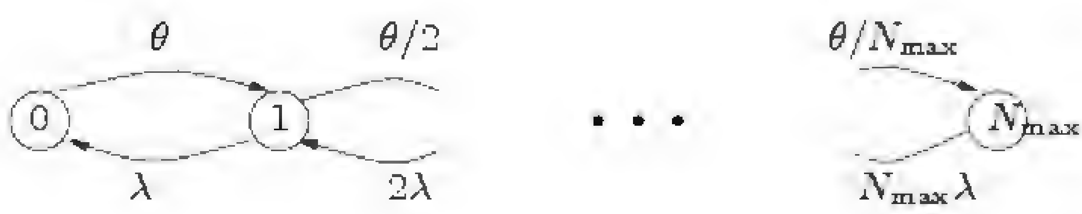
Figure 1: Cartel birth, death and detection process



2.3. Process specification

The process already described is markovian, inter-arrival times depending on the state of the system: at time t, if there are already N(t)=n cartels likely to be detected, the arrival of a new cartel occurs with a $q_n.\theta$ intensity. For each new cartel subjected to the detection process, the detection duration follow an exponential law with parameter λ. Therefore, if n cartels are likely to be detected, the time to move to the state (n-1) is the minimum of n variables i.i.d. exponentially distributed with parameter λ, i.e. an exponentially distributed law with parameter $n.\lambda$. Hence, the transition rate from the state n to the state (n-1) is $n.\lambda$. This birth and death process[7] admits the following state transition diagram:

Figure 2: State transition diagram



This process is an infinite server queue (M/M/∞ type), with varying entering rates.

[7] In this case, death is similar to detection. Death from natural causes is not taken into account, as we only focus on detection.

- *At steady state, the law governing the number of cartels N subjected to the detection process at any time is defined as:*

Let denote π_n =Prob (N=n) and $r = \frac{\theta}{\lambda}$. We can show that:

$$\pi_n = \frac{q_0 \times \ldots \times q_{n-1}}{1 \times \ldots \times n}\left(\frac{\theta}{\lambda}\right)^n \pi_0 = \frac{1}{(n!)^2} r^n . \pi_0$$

With:

$$\pi_0 = \frac{1}{\sum_{n=0}^{N_{\max}} \frac{r^{n,}}{(n!)^2}}$$

- *The global probability of detection is therefore:*

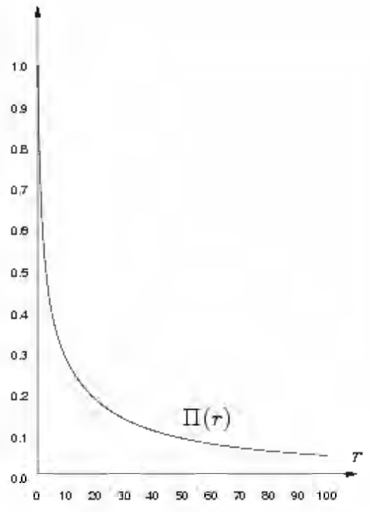
Let denote Π the global probability of detection:

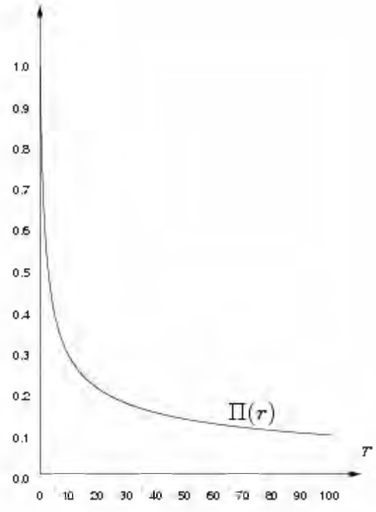
$$\Pi = \sum_{n=0}^{N_{\max}} \text{Prob (being detected| N=n). Prob(N=n)} = \sum_{n=0}^{N_{\max}} q_n \pi_n$$

This implies:

$$\Pi(r) = \frac{\sum_{n=0}^{N_{\max}-1} \frac{r^n}{(n!)^2 (n+1)}}{\sum_{n=0}^{N_{\max}} \frac{r^n}{(n!)^2}}$$

Figure 3: evolution of Π according to $r = \frac{\theta}{\lambda}$ for $N_{\max} = 5$ and $N_{\max} = 100$





The limits found confirm our intuition:

- When r tends to 0, i.e. the birth rate is very low compared to the detection rate; the antitrust authorities can detect all new cartels.

- When r tends to infinite, the antitrust authorities are overwhelmed, more and more cartels are not subjected to the detection process and the global probability of detection tends to 0. Nevertheless, we note on figure 3 that the convergence towards zero is very slow. Therefore, Π increases with λ.

- *The instantaneous probability of detection of a cartel that will be detected in fine:*

The instantaneous probability of detection of a cartel for which event E occurs is λ. Hence, λ is the instantaneous probability of detection of a cartel that will be detected *in fine*.

- *The global instantaneous probability of detection* π *:*

A cartel that does not know whether it will be detected or not (i.e. if it is the event E or the event $\overline{E}$ that occurred) perceived the following instantaneous probability of detection:

$$\pi = E_N[q_N.\lambda] = \lambda.E_N\left[q_N\right] = \lambda.\sum_{n=0}^{+\infty} q_n.\pi_n$$

This implies:

$$\pi = \lambda.\Pi$$

We note that λ is an upper bound of π.

To sump up, it appears that one must distinguish between three different values:

- The instantaneous probability of detection for a cartel that will be detected: λ
- the global instantaneous probability of detection: π
- the global probability of detection: Π

Bryant and Eckard (1991) estimated the instantaneous probability of detection for cartels that will be detected, which corresponds to λ. Considering that some cartels are never detected and remain unknown, the global probability of detection is necessarily inferior to λ[8]. We formalized this intuition, proving that λ is an upper bound of the

[8] Buccirossi & Spagnolo (2005) where the first to note that λ is the probability of detection in a given year if all cartels were detected with probability one. If 10 % were detected *in fine*, the global probability of being detected in a given year would amount to one tenth of λ. If 1 % of cartels were detected, it would equates to one hundredth of λ.

global instantaneous probability of detection. Furthermore, the global probability of detection varies positively with λ.

2.4. Birth and death process for the estimation

Among all cartels born, we limit ourselves to the study of the sub-population of cartels eventually detected, these cartels being subjected to a simple life and death process (considering death as detection). The detection process is still characterized by the parameter λ. But the parameter that specifies the birth process is θ'= (θ|the cartel will be detected). It is linked to the θ parameter by the following relationship:

$$\theta' = E_N[q_N.\theta] = \theta.E_N\left[\frac{1}{N+1}\right] = \theta.\Pi$$

We can note that $\theta' < \theta$: there are more cartels born than cartels finally detected - as some cartels remain unknown. As we do not have data on undetected cartels, we can only estimate the detection and birth process which applies to the subpopulation of detected cartels - of parameter λ and θ'.

- First, λ is an upper bound of the global instantaneous probability of detection. And the global probability of detection varies positively with it. Hence, the higher λ, the greater the probability a cartel will be detected.
- Second, it is likely that, in their decision making, firms take into account the parameter λ, as the global probability of detection is unknown.[9]

In this article, we will estimate the instantaneous probability of detection for a cartel that will be detected *in fine*, i.e. the value of the λ parameter. Our estimates are based on a sample of all the cartels detected and convicted by the European Commission from 1969 to 2007.[10] After the presentation of the methodology - regarding data processing and statistical estimation - we present the results of our study.

[9] Particularly, if the value of λ is common knowledge, thanks to the work of economists, firms do not have a better knowledge of Π, the global probability than we do. Thus, managers may not take their decision on the basis of this global probability of detection Π.

[10] From a database we created.

3. Methology

This work is based on the detection duration - duration between birth and detection - of cartels convicted by the European Commission, as no data exist on undetected cartels or non convicted ones.[11] Our sample encompasses 86 cases of cartels that have affected European trade - at least two members states and/or the trade between members affected[12], and convicted by the European Commission between 1969 and 2007.[13]

3.1. Computation of cartels detection duration

Lifetimes and detection duration

Cartels can break up because of detection or because they die "naturally". We aim to estimate the probability of detection of a cartel, which corresponds to the period from the birth of the cartel to its detection. If the cartel is detected while it is still active[14], before its natural death, then cartel lifetime equates its detection duration. But, when the cartel terminates from natural causes[15] and is detected afterwards, detection duration is no more similar to lifetime, and we must reprocess these data. First, we will present the methodology related to lifetime computation, when it corresponds to detection duration. Then, we will study the case of naturally dead cartels, detected *ex post*. Concerning cartels detected alive - and therefore dead because of detection[16]- we have computed cartels lifetimes in days, using the estimation made by the European Commission to compute fines and reported in its decisions. In a number of cases, it is presumed that the cartel lasted longer than the duration used by the Commission-because of lack of proof. Therefore, durations used in our estimation may be underestimated and should be considered as lower bounds. In particular, the begin date of the cartel corresponds to the date for which the first evidence of collusion were found, and not necessarily to the actual starting date of the conspiracy. It is likely that the cartel date of birth is anterior to

[11] Most of detected cartels are finally convicted, thanks to the introduction of leniency notice and the reinforcement of the investigation powers of antitrust authorities.

[12] Criteria of affected trade as defined by the Commission in its Guidelines on the effect on trade concept contained in Articles 81 and 82 of the Treaty. *Official Journal C 101, 27.04.2004, p. 81-96.*

[13] The first cartel convicted of our sample is the Quinine cartel in 1969 and the last one is the elevator one in February 2007.

[14] Regarding cartel detection, we can distinguish between sector inquiry or a targeted one. These targeted inquiries can originated from a complaint from competitors or clients, or from a denunciation, which plays a key role since the introduction of leniency notice in the European Union in 1996, see Combe & Monnier (2007b).

[15] Regarding cartels terminating from « natural » causes, we can distinguish cheating or withdrawal, the arrival of one or several new players in the market, others supply or demand changes-demand increase, advances in technology etc. - which influence the benefits of collusion, can provoke a break up.

[16] These cartels represent 80 cases on the 86 cartels of our sample, which means the great majority.

the date claim by firms or put forward by the Commission. The fine imposed on an undertaking being positively correlated to its involvement duration in the cartel, it is in the firm interest not to disclose the actual begin date of the collusive agreement.[17]

Sometimes, it can happen that collusion goes on after the detection of the cartel by antitrust authorities.[18] Nevertheless, we will not take into account this rare phenomenon, difficult to assess. In our study, we suppose that detection always triggers the death of the cartel. In all other cases, to calculate duration, we consider the ending date for which it has been proven that firms have stopped colluding.

Furthermore, the duration of each undertaking own involvement in the cartel is not necessarily the same. Therefore, we use the global duration of the cartel, as indicated on the Commission's decision.

Last, we must explain how we dealt with successive or intertwined cartels or agreements. In a lot cases, firms have agreed to collude on several markets, i.e. on several products or geographic areas. [19] Moreover, it happens that some ended agreements are followed by new ones - successive agreements. [20] We can also distinguish between formal agreements and/or concerted practices - implying most of the time exchange of information - related to price fixing or market sharing. These practices are regrouped under the aegis of a sole cartel. Usually, the decision of the Commission reports only the global duration of the cartel and there is no distinction in it between different agreements, as the ruling of the Court of First Instance, refers to the concept of complex infringement.[21] Nevertheless, in the three following cases: Vitamins

[17] For more details, Levenstein & Suslow (2002) discuss the difficulty to date the beginning and the end of a cartel and make a review of the literature on this topic.

[18] For instance, in its decision 94/599/CE regarding the PVC cartel in 1994- § 49 of the decision- the Commission explains that: "*in the absence of information from the producers, it is not even possible to establish whether or not the collusion - in some form or other - has ever ended. Clearly the cartel continued after the Commission carried out its first investigations into the PVC sector in late 1983. The document found at Atochem shows that monitoring of sales quotas was being operated and information exchanged as late as May 1984. The phenomenon of initiatives involving several producers simultaneously attempting to raise price levels to a particular level was still being reported in the trade press at the time of the investigation in 1987*". Levenstein and Suslow (2006) also evoke the case of the Organic Peroxides, convicted in 2003.

[19] For instance, the Vitamins cartel lasted for 10 years and relates to agreements on nine vitamins and four chemicals, and the 22 producers involved did not participate to all the agreements.

[20] See for instance the Citric Acid cartel case.

[21] Accordingly the ruling of the Court of First Instance "*in the context of a complex infringement which involves many producers seeking over a number of years to regulate the market between them, the Commission cannot be expected to classify the infringement precisely, for each undertaking and for any given moment, as in any event both those forms of infringement are covered by Article [81] of the Treaty*", Judgment of the Court of First Instance of 20 April 1999 in Joined Cases T-305/94 to T-

Cartel, Special Graphite Cartel, and Peroxygen Cartel, the Commission distinguishes between several agreements, denoted as *sub-agreements* - on different markets - of the same cartel, dividing up their durations. For these three cartels, we calculated the mean duration of the cartel – identifying and excluding naturally dead sub-agreements. For all other intertwined cartels, we take the global duration of the cartel, as reported in the decision of the Commission.

Most decisions contain precise begin and end dates - day, month, year. But in some cases, only the year is given or the most precise identification is to the month[22]. Therefore, we used two methods to calculate cartel duration. The first method defines a minimum duration (DUR1) to be the period from the latest begin day to the earliest end day of the cartel - for instance if the decision indicates that the cartel began in 1971 and continued to at least October 1975, the latest begin day is December 31, 1971 and the earliest end day is October 1, 1975. The second method defines the maximal duration (DUR 2) to be the period from the earliest begin day to the latest end day. In the above example, the earliest begin day is January 1, 1971 and the latest end day is October 31, 1975. These two measures give us a range of values and each is defined to include all cases in the sample. This method also corresponds to the methodology used by Bryant and Eckard.

These strict hypotheses - in particular the use of lifetimes reported to compute fines - warrant that our results are reliable, as they are not based on assumptions or even strong presumptions. These durations correspond to lower bound, implying a possible overestimation of the probability of detection. The results of cartels lifetimes computations are sump up in the following table.

Table 1: Cartel duration

	Median	**Mean**	**Standard Error**
DUR Min	5,5	7,46	5,82
DUR Max	5,98	7,8	5,9

307/94, T-313/94 to T-316/94, T-318/94, T-325/94, T-328/94, T-329/94 and T-335/94 *Limburgse Vinyl Maatschappij and Others v Commission.*

[22] Particularly in the case of not yet published decisions.

Table 2: Comparison to other studies on cartel duration

	Mean Duration	Median	Standard Error	Nb of cases
Bryant & Eckard (1991)	6.2	4.7	na	184
Zimmerman & Connor (2005)	6.3	4.4	na	166
Levenstein & Suslow (2006)	7.5	na	5.4	72
na: non available				

The average lifetime of a European cartel is about 7.5 to 7.7 years - the median is 6 years, so as the standard error - which corresponds to the cartel duration computed in other works[23], particularly in Levenstein & Suslow (2006).[24]

3.2. Naturally dead cartels

In some cases, the date at which the cartel breaks up does not correspond to its detection, and it happens that firms can prove that the cartel was no more active since many years. In our sample, contrary to what economic theory suggests[25] convicted cartels are most of the time still active when the Commission starts its investigations, and terminate collusion after this intervention. Only 6 cartels[26] and 10 sub-agreements of our 86 convicted cartels are naturally dead.[27] Contrary to Bryant and Eckard we computed detection durations of these naturally dead cartels. Their lifetimes are shorter than their detection durations, by definition. Hence, we add to the computed lifetimes, the duration between the natural death of the cartel and its detection. Therefore, the data related to those cartels are similar to the one related to cartels detected alive. The estimated probability is therefore a probability of detection. This specific processing also allows us to focus on two processes - birth and detection - and to avoid the complex distinction between cartels naturally dead and detected *ex post* and cartels dead because of detection.

[23] The minimum duration is less than three months for the French Beef Cartel and the longest one which last 29 years is the Organic Peroxide Cartel. Most of our cartels are dead because of prosecution. Therefore detection durations are almost similar to cartels durations in our study.

[24] Their work is based on cartels convicted by the DOJ and the European Commission.

[25] According to Stigler (1964), once firms have decided to form a cartel, each undertaking has an interest to cheat and to lower its price. See also Armentano discussion on cartel instability (1996). But d'Aspremont and Jacquemin (1996) showed that Stigler had neglected the impact of a withdrawal or of an entry of an undertaking on prices and profits.

[26] The Quinine Cartel condemned in 1969, the Zinc Producers Group Cartel condemned in 1984, the FENEX Cartel condemned in 1996, the Ferry Operators Cartel condemned in 1996, the Citric Acid Cartel 2001, the Peroxygen Products Cartel condemned in 1984 and the Hydrogen Peroxide and Perborate (PBS) Cartel condemned in 2006.

[27] Nine sub-agreements of the vitamin cartel are dead before their detection because of the increase in Chinese imports, and one sub-agreements of the Specialty Graphite Cartel.

3.3. Is detection duration a random variable?

Bryant and Eckard regressed cartels lifetimes on two different explanatory variables: the number of undertakings involved and their market shares. Comme aucune de ces variables n'est explicative, les auteurs en concluent que la durée de vie d'un cartel peut être traitée comme une variable aléatoire. Neither variable is correlated with their cartel duration measures. Thus, the authors conclude that cartel duration can be viewed as a random variable.

According to them, cartel duration should be longer the fewer the number of firms involved and the larger their market share, *ceteris paribus*. While these hypotheses are clear for cartel natural duration - i.e. for cartel terminating for "natural" causes, e.g., cheating, or irreconcilable differences among conspirators. It is less clear that they apply to cartel dead by detection.

As for us, we regress cartel detection duration on four explaining variables[28] - number of undertakings, professional organization involvement, cartel dimension (global, European or national) and industry specific conditions - which economic theory[29] and empirical studies[30] suggest should be related to cartel duration. Particularly, these factors can apply to detection duration and therefore to a sample of cartels terminated as a result of investigation[31]. Indeed, the greater the number of firms involved, the more likely is detection: numerous pieces of evidence, higher risk of denunciation. The industry in which the cartel operates could also influence the detection process. Moreover, cartel dimension can contribute to make detection more likely.[32] As cartel dimension widen, detection duration should decrease. Indeed, international - or global - cartels can be detected both in Europe and in the United States. European cartels can be caught by any national competition authority inside the European Union. Last, the intervention of a professional organization should influence the probability for a cartel to be detected, but it is difficult to predict how - a better organization implies a lower risk of detection but also a greater visibility towards competition authorities. Indeed, some markets are more transparent than others, and the detection of anticompetitive

28 It corresponds to cartel duration in most of cases.
29 Motta (2004) analyses the main factors of stability of cartels.
30 See Zimmerman & Connor (2005), Levenstein & Suslow (2006), Combe & Monnier (2007) for an empirical study the determinants of cartel duration.
31 As a matter of fact, the determinants of cartel detection are not necessarily the same as the determinants of cartels natural breakup.
32 In some cases, it can be difficult for national antitrust authorities to convict international cartels because of the problems related to the extraterritorial application of antitrust law. See Jenny (2003).

collusion should be easier in these industries - that can be subject to a specific monitoring from antitrust authorities. Neither variable is correlated to our cartel duration measures at a 5 % threshold.[33] As Bryant and Eckard, we therefore consider detection duration as a random variable. And this assertion justifies the fact that we apply a single birth a death process on the overall sample.

4. Estimation and empirical results

4.1. Estimation of the instantaneous probability of detection

We use a birth and death process, a continuous Markov chain, to describe N(t), the number of cartels alive at a time t. Suppose at time t=0 there exist no cartel. A any time t>0, we suppose that in a short interval of time from t to t+h, only three changes in N(t) are possible for h sufficiently small:

-Let N(t) changes from N(t) to N(t)-1 with probability λ.h+o(h)

-Let N(t) changes from N(t) to N(t)+1 with probability θ.h+o(h)

-Let N(t) remains unchanged with probability 1-($\lambda+\theta$).h+o(h)

Li denotes the random variable relating to the detection duration of the ith cartel and A_i, the duration between the birth of the (i-1)th cartel and the birth of the ith cartel - which corresponds to inter-arrival times between the births of successive cartels.

In such a process, the $(L_i)_{i=1..}$ and the $(A_i)_{i=1..}$ are independently and exponentially distributed with means $1/\lambda$ and $1/\theta$ respectively:

$$\forall i=1..\ n,\ Li\sim Exp(\lambda)$$

$$\forall i=1..\ n,\ Ai\sim Exp(\theta)$$

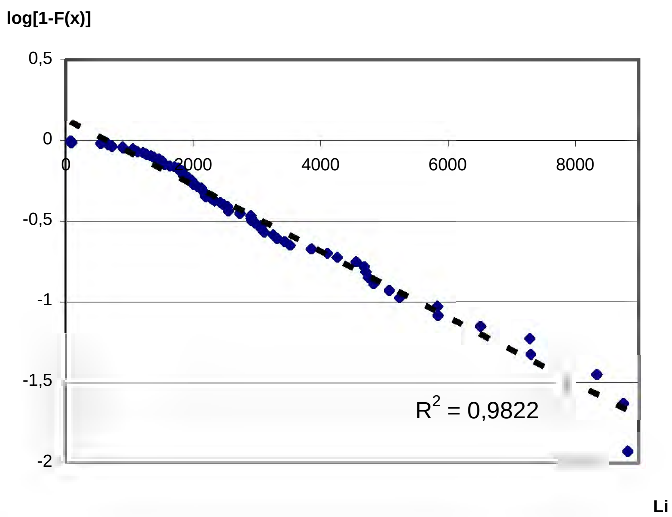
To justify the use of exponential laws, and to see how close our assumption of exponentially fits the inter-arrival times and duration data, we make the following verification: if the random variable L_i is exponentially distributed with means $1/\lambda$, its distribution function is F(x)=1-exp(-λ x) and therefore, log[1-F(x)]=- λ x. We do not know F(x), but we can estimate the empirical cumulative distribution function $\hat{F}(x)$ = (number of observations $\leq x$)/(total number of observations). In order to verify that the « Li~Exp(λ) » we analysis the figure of the function x→log[1- $\hat{F}(x)$]. For an

[33] See Appendix A.

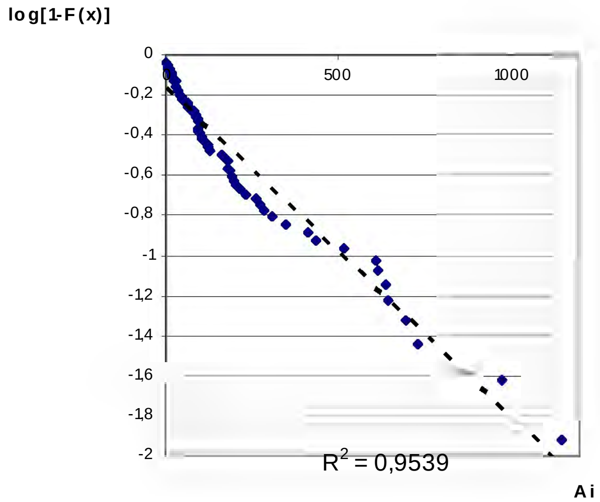
exponential distribution, it should be approximately linear in x, which is verified on the figures below. We apply the same reasoning for the A_i. The R^2 are very high: 0.9822 for detection duration and 0.9539 for inter-arrival times between successive births .These results justify our choice of exponential process.

Figure 4: Exponential fit of detection durations inter-arrival times

Exponential fit of detections durations



Exponential fit of cartels inter-arrival times



Furthermore, we suppose that the process begins at time T_0, which is unknown, but that we observe the process for cartels dead between $[T_1, T_2]$ with $T_2>T_1>T_0$. It implies that we have censored data - as cartels alive both at time T_2 and T_1 won't be observed - and it makes the estimation more complex.

We use the maximum likelihood estimation method for right censored data. Therefore, the parameters λ and θ are estimated by the maximum likelihood method, as derived as followed[34]:

$$V(L_1,\ldots,L_n) = \theta^n \lambda^n \exp[-\theta(T_2 - T_1)]\exp[-\lambda\sum_{i=1}^{n} L_i]\exp(w)$$

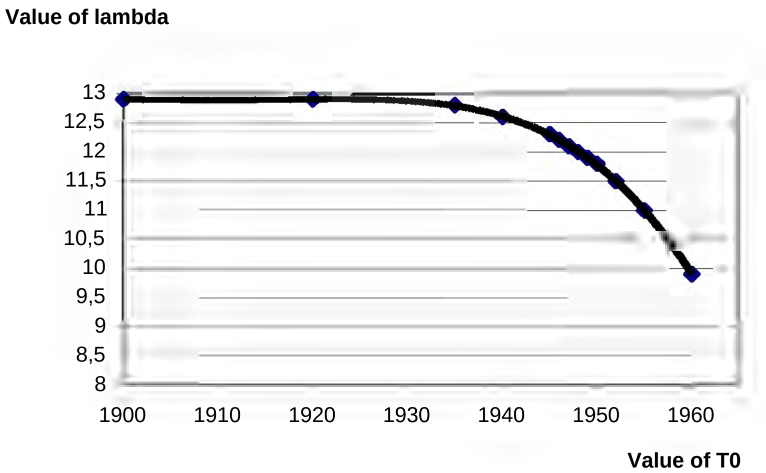
With $w = (\theta/\lambda)\exp[-\lambda T_1]\{1-\exp[-\lambda(T_2 - T_1)]\}$.

And λ is an estimate of the instantaneous probability of detection of cartels that will finally be detected.

4.2. The beginning of the process

As we can notice, the estimation of λ is function of the value of the T_1 and T_2 parameters, themselves depending on the value of T_0. Therefore, the method requires us to specify not only the sample period but also how long the process had continued before we began our observation. Instead of making a unique choice for T_0, we estimated the value of λ for different values of T_0. It appears that for value of T_0 inferior to 1930, the estimation of λ is no longer sensible to the choice of T_0[35]. Indeed, as one can observe on the figure below, any choice of T_0<1930 allow us to consider that the birth and death process has reached a steady state. Therefore we suppose that T_1 is large enough, the process has reached a steady state.

Figure 5: Lambda sensitivity to the choice of T_0

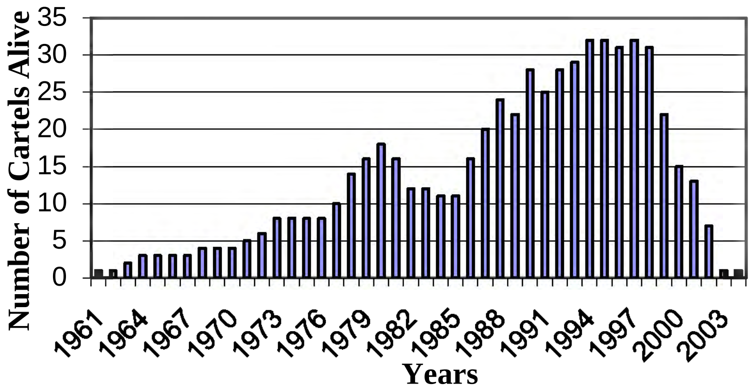


[34] See APPENDIX Bryant & Eckard (1991).

[35] Bryant & Eckard (1991) estimate their parameters for T0 values ranging from 1861 to 1936, and show that the estimation of the process reaches a steady state if we consider T1 as large enough.

Under the hypothesis related to the simple birth and death process model[36], and given the censored data, the number of cartels alive at time t, N(t) with $T_1<t<T_2$ has a Poisson distribution with mean $(\theta/\lambda)\{1-\exp[-\lambda t]\}\{1-\exp[-\lambda(T_2-t)]\}$, which can be simplified in $(\theta/\lambda)\{1-\exp[-\lambda(T_2-t)]\}$ under the additional assumption that T_1 is large enough. In this case, as t gets closer to T_2, N(t) should decrease, which is empirically verified, as we can see on the figure bellow:

Figure 6: Number of cartels alive at Time t



4.3. Results

Table 3: Parameters estimates

		λ*	1/λ**	θ***	1/θ****
DUR1	Days	0.000363	2753	0.02	50
	Years	0.132	7.533	7.3	0.137
DUR2	Days	0.000347	2880	0.02	50
	Years	0.129	7.702	7.3	0.137

* Probability of cartel detection on a given day or year

** Mean detection duration

*** Probability of cartel birth on a given day or year

**** Mean inter-arrival times

The results of the estimation of our parameters are sum up in table 3. As we can see, the detection duration is on average 7 years - 1/λ corresponds to the mean detection duration - and a new cartel eventually detected is born every 6 months, as 1/θ represents

[36] The L_i and A_i are independently and exponentially distributed: $\forall i=1..n$, $L_i \sim Exp(\lambda)$ et $A_i \sim Exp(\theta)$.

mean inter-arrival times in days or years. The probability of detection in a given year conditional on being detected is between 12.9 % and 13.2 %, which represents an upper bound of the global probability of detection. Therefore, the probability of detection in a given year is at most between 12.9 and 13.2 %. Bryant and Eckard showed that the average cartel lasted about five to seven year, and that a new cartel that will be finally detected was born about every 54 days - seven per year on average. Their probability of getting caught in a given year for a cartel, given that it will finally be detected, was between 13 % and 17 %.

5. Conclusion

Bryant & Eckard (1991) were the first to estimate probability of cartel detection. Their estimation was based on an American sample of cartels indicted by the DOJ between 1961 and 1988. They obtained an annual probability of detection conditional on being detected between 13 % and 17 %. Using the same framework, we calculated the detection duration and the probability of detection - if all cartels were eventually convicted - over the sample of all the cartels convicted by the European Union from 1969 to 2007. Our detection duration is about 7 years and a new cartel, which will eventually detected, is born every 6 months The probability of getting caught in a given year, conditional on being detected, is between 12.9 % and 13.2 %, which represents an upper boundary to the global probability of detection. Therefore, the probability of detection in a given year is at most between 12.9 % and 13.2 %.

On the basis of these two studies, it is interesting to compare the probability of detection between geographic areas -and therefore to evaluate the respective efficiency of various antitrust policies. At first glance, the probability of detection being higher in the United States, one could conclude that the American antitrust authorities are more efficient in detecting cartels than the European Commission.

Nevertheless, differences in the methodology, particularly relating to data collections, may also explain this discrepancy, regardless efficiency criteria:

- Bryant and Eckard used data less precise than ours. As a matter of fact, starting and ending dates of their sample are vague, which gives them a large range of probabilities, and undermines the significance of the spread between our results and theirs.

- Regarding naturally dead cartels, our data processing enables us to estimate detection durations, which is not the methodology followed by Bryant and Eckard. As they do not differentiate between naturally dead cartels and cartels terminating because of detection[37], their estimation is biased. They estimate a death probability, not necessarily equivalent to the probability of detection, if some cartels died naturally and were detected ex post. By definition, these cartels have shorter lifetimes than detection duration.[38] Therefore, their probability could be overestimated as their sample might include such cases.
- The study of Bryant and Eckard is based on American cartels-cartels indicted by the DOJ- most of which being probably national cartels. Regarding our sample, more than half of the cases are European cartels -at least two affected members- a quarter of the cases are global -defined as affecting Europe as well as at least one other major region of the world-, and less than 25 % of cartels are national –affecting a single member state and European trade. Hence, more than two third of the sample relates to international cartels. As Connor (2003) pointed out, durations of international cartels are typically longer than national ones.[39]

We could also assess antitrust efficiency in detecting cartels across time. Particularly, the introduction of leniency programs in the European Union in 1996, should have contributed to reinforce the probability of detection. We do not have enough hindsight, and not enough data, to estimate the probability of detection over a recent period. It is too soon for us to assess these long terms effects, but it is an important topic for future research, as it would enable us to assess rigorously the effect of leniency programs on cartels detection, and therefore to evaluate precisely their efficiency- which has never been down[40]. We can already note that after 1996, in eight years, 40 cartels were detected, which corresponds to 5 detection per year on average, whereas before 1996 -in 28 years- we count 46 detected cartels, implying 1.64 detection per year in average. This sharp increase of detected cartels could be explained by the introduction of

[37] Their estimates are based on lifetimes and not on detection durations.
[38] For instance, regarding the vitamin cartel, naturally dead sub-agreements were shorter than the ones terminated because of the cartel detection.
[39] Connor showed that global cartels have a lifetime 55 % higher than lifetimes of other cartels, and that regional cartels have a lifetime 40 % higher than national ones. In our sample, most of cartels were detected while alive and broke up after antitrust intervention. Hence, in our study, cartels durations correspond approximately to detection durations. It allows us to refer to others studies on cartels lifetimes and to compare our work to the one of Bryant and Eckard.
[40] To our knowledge.

leniency programs[41]. Indeed, in the first time, if these programs are efficient, their introduction should have contributed to an increase of the probability of detection, as these programs imply a reduction of investigations costs, they facilitate inquiries and evidence collection, and jeopardize cartel stability. On the long run, these programs should dissuade cartel formation[42] and therefore, we could also observe a reduction in the number of detected cartels -if fewer cartels form. Nevertheless, as Motta and Pollo (2003) showed, these programs can also have a counter productive effect. Indeed, reducing the expected fines help sustain collusive agreements and foster collusion.

[41] See appendix B. Nevertheless, this increase of the number of detected cartels should be put into perspective with the number of birth. As some cartels remain undetected, we only have the subpopulation of cartels dead from detection.

[42] Aubert, Rey, Kovacic (2006).

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APPENDIX

A- Determinants of Duration

Variables		Parameter estimate	Standard Error	t value	Pr > $\lvert t \rvert$
Intercept		3064.52389	624.20184	4.91	<.0001
Nb Undertakings		36.57548	33.20373	1.10	0.2741
Trade Association		-629.09560	557.77615	-1.13	0.2629
Dimension	Ref= Europe				
	Global	71.26517	653.59000	0.11	0.9135
	National	141.74111	615.62781	0.23	0.8185
Industry	Ref= Europe				
	Metal & non-metallic products	-422.50164	773.94921	-0.55	0.5867
	Machinery & equipment	-362.96977	770.09302	-0.47	0.6388
	Construction-textile	1395.29539	1380.11512	1.01	0.3152
	Services	-821.16814	761.09654	-1.08	0.2840
	Food products beverage and tabacco	-1099.39343	840.50226	-1.31	0.1948

B- Number of Detection (3 Years Moving Average)

Number of detected cartels

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